TRANSACTIONS
OF THE
ILLUMINATING ENGINEERING SOCIETY

FOUNDED
IN LONDON
1909

INCORPORATED
1930

LIBRARY
FEB 15 1949

CONTENTS

Page

Design of Contact Lights for Aerodrome Runways, by H. J. Turner, B.Sc., A.M.I.E.E. *(Fellow)* - - - 1

Additions to List of Members - 15

VOLUME XIV
No. 1 — 1949

32 VICTORIA ST
LONDON, SW1

Annual Subscription to Non-Members - £2.2.0
Price per Number to Non-Members - 5s. 0d.

The I.E.S. Council and Committees
Session 1948-1949

Council

President :—J. M. WALDRAM, B.Sc. (*Fellow*).

Vice-Presidents :—E. C. WALTON, B.Eng., Ph.D., E. W. MURRAY (*Fellow*), J. N. ALDINGTON, B.Sc., Ph.D. (*Fellow*).

Members of Council :—

Elected Members:—

C. J. ALLDERIDGE, A. D. S. ATKINSON, H. S. BARLOW, C. R. BICKNELL, H. BRIGHT, L. J. DAVIES, G. H. GILES, H. F. GILLBE, C. E. GREENSLADE, T. S. JONES, S. D. LAY, E. C. LENNOX, H. A. LINGARD, J. H. NELSON, A. J. P. PASHLER, A. G. PENNY, L. C. RETTIG, J. S. SMYTH, W. T. F. SOUTER, J. F. STANLEY, W. R. STEVENS, P. C. SUGG, S. G. TURNER, F. WALKER.

Ex-Officio Representatives of Centres:—

L. BURDES (*Bath and Bristol*), W. J. P. WATSON (*Birmingham*), J. S. CHILDS (*Cardiff*), S. G. BATT (*Edinburgh*), D. ROSS (*Glasgow*), J. DAVOILE (*Gloucester and Cheltenham*), J. D. GREEN (*Leeds*), F. JAMIESON (*Leicester*), O. C. WAYGOOD (*Liverpool*), H. ATHERTON (*Manchester*), H. L. JAMES (*Newcastle*), E. G. PHILLIPS (*Nottingham*), B. BINGHAM (*Sheffield*).

Hon. Treasurer :—
J. G. HOLMES.

Hon. Secretary :—
H. C. WESTON.

Hon. Editor of Transactions :—W. R. STEVENS.

All Past-Presidents of the Society are *ex-officio* Members of Council.

Committees

GENERAL PURPOSES COMMITTEE: J. M. Waldram (*President*), J. G. Holmes (*Hon Treasurer*), H. C. Weston (*Hon. Secretary*), J. W. T. Walsh (*Past-President*), E. C. Walton, E. W. Murray (*Vice-Presidents*), C. J. Allderidge (*Birmingham Centre*), H. Atherton (*Manchester Centre*).

PAPERS COMMITTEE: A. D. S. Atkinson, C. R. Bicknell, T. S. Jones, A. G. Penny, F. C. Smith, J. S. Smyth, P. C. Sugg.

EDUCATION COMMITTEE: R. O. Ackerley, H. S. Barlow, A. Cunnington, P. Good, C. E. Greenslade, W. J. Jones, S. D. Lay, J. T. MacGregor-Morris, F. C. Smith, W. R. Stevens, J. W. T. Walsh.

I.E.S. CODE COMMITTEE: R. O. Ackerley, C. R. Bicknell, J. H. Nelson, F. C. Smith, J. S. Smyth, W. T. F. Souter, J. F. Stanley, J. W. T. Walsh, H. C. Weston.

DEVELOPMENT COMMITTEE: R. O. Ackerley, A. D. S. Atkinson, T. S. Jones, S. D. Lay, A. G. Penny, L. C. Rettig, S. G. Turner.

AREAS JOINT COMMITTEE: One representative from each Centre.
Council's Representatives: C. R. Bicknell, J. H. Nelson, W. R. Stevens.

(The President, Hon. Secretary and Hon. Treasurer are *ex-officio* members of all committees.)

Secretary :—G. F. COLE, 32, Victoria-street, London, S.W.1.

Design of Contact Lights for Aerodrome Runways

By H. J. TURNER, B.Sc., A.M.I.E.E. *(Fellow)*

Summary

An account is given of methods of calculating the light distribution required from aerodrome runway contact lights with particular reference to foggy weather. The limitations on intensity and light distribution imposed by mechanical and electrical conditions and the relative merits of flush-mounted and elevated lights are discussed. Consideration is given to the light distribution in directions other than those from which the lights are seen during approach and landing.

(1) Assumptions

(1.1) Factors to be Considered

In deciding the form of the light distribution required from a contact light, three principal factors must be taken into account:—

(i) The "geometry" of the runway and approach way, i.e., the dimensions of the runway, the position of the fittings on it and the manner of approach of the aircraft. Under this heading various assumptions will be made which are in accord with present-day practice. Not all aircraft, of course, use the same method of approach, but aerodromes in general have to cater for all types of aircraft and so eventually some compromise [suitable to all] will have to be decided.

(ii) The state of the weather, i.e., the visual range and the brightness of the background against which the lights will be seen, from which can be derived the minimum intensity of signal which can be seen under flying conditions.

(iii) The practical limits of intensity and light distribution which can be obtained from the fitting. These factors are determined mainly by mechanical requirements and the economics of cabling and electric supply.

Mechanical requirements include the important question of whether the lighting fittings are mounted "flush" with the runway surface, i.e., having a projection of not more than one or two inches, or whether they are of the "elevated" type mounted on a pedestal two or three ft. high. The relative merits of these two forms are discussed in more detail in section 4, and it will be sufficient to state here that the flush type may be placed anywhere on the paved surface, but, because of their restricted size, their light output is limited. The elevated types have no mechanical restriction on light output, but they must be positioned off the paved runway. Calvert[10] states that with adequate approach lighting arrangements the intensities obtainable from flush-mounted lights should be sufficient. He admits at the same time that this view is at variance with American opinion which favours the use of high intensities obtainable only from elevated lights. In some areas the weather may be a deciding factor; for example where the runway is snow covered for long periods the use of elevated fittings may be the only solution if a permanent installation is required. The calculations which follow are based on the

Communication from the Staff of the Research Laboratories of The General Electric Company, Limited, Wembley, England. The manuscript of this paper was received on September 16, 1948, and in its revised form on November 24, 1948.

intensities and layout obtainable with flush fittings, but the methods used apply equally to the elevated type.

The three factors will now be discussed in more detail.

(1.2) The Geometry of the Runway and Approach

For the purpose of calculation the following assumptions have been made (see also Fig. 1):—

(a) That the runway is not less than 150 ft. wide, that the spacing between lines of contact lights is 150 ft.[1, 2], and that the distance between individual fittings is 100 ft.

(b) That the aircraft is approaching on an angle of glide of 3 deg. and the touch-down point of this path intersects the centre line of the runway at a point 1,000 ft. from the threshold.

(c) That the aircraft is at a height of 100 ft. when the pilot first needs to see the contact lights. At least three lights on either side must be visible to give the pilot the "line" of the runway and to permit him to keep level.

A preliminary consideration of the light output and intensities likely to be obtained in practice, the limiting visibility conditions and the pilot's view of the pattern of lights during the approach leads to the conclusions that in limiting visibility the lights cannot be visible above a height of 100 ft. The diagram of Fig. 4 shows that for a 3 deg. approach the aircraft will be 900 ft. from the threshold when it is at a height of 100 ft. In this position the pilot will still be guided by a high intensity approach lighting pattern, so that during these last stages of descent (equivalent to about nine seconds' flying time at 120 m.p.h.) the lighting pattern will change

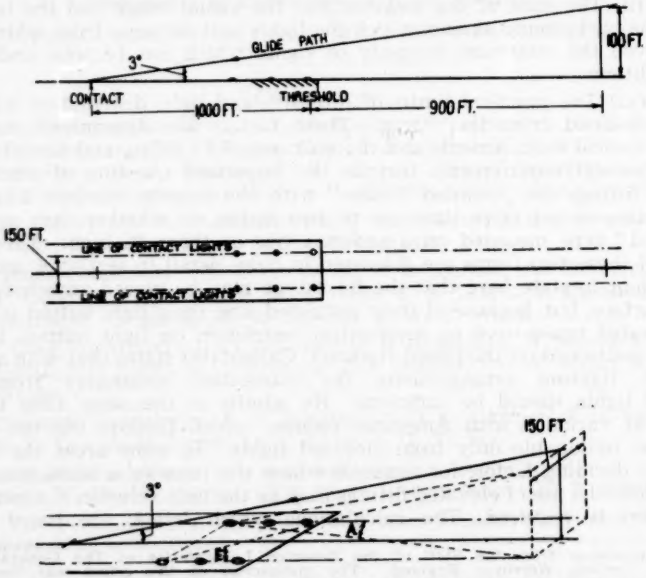

Fig. 1. Position of aircraft with respect to runway.

from one formed by the approach lights to one given by the contact lights. Calvert[10] has suggested an approach lighting pattern formed of a single centre line of lights (along an extension of the centre-line of the runway) with horizontal cross bars at right angles. He suggests further that the centre line could with advantage be continued along the runway itself to aid the transition from the approach lighting pattern to the runway lighting pattern.

(d) That at a height of 100 ft. the maximum lateral error in the position of the aircraft is 75 ft. to either side—i.e., that the pilot's view will be from a point somewhere between vertical planes through the two lines of fittings.

(e) That vertical " errors " in the position of the aircraft are not allowed for in the same way as horizontal deviations. This does not mean, however, that they are ignored or that the aircraft must be exactly in a plane through the ideal glide path for the lights to be visible. In limiting visibility there is a natural tendency for the pilot to " hold off." If he does this to such an extent in the early stages of approach that he does not see the approach lighting, it is unlikely that he will ever see the contact lights because, as stated before, these will probably not be visible above a height of 100 ft. If, however, the aircraft comes within range of the approach lighting and is duly guided along the approach, the " hold off " will take the form of overshooting the glide path somewhat and coming down a parallel path a little distance ahead. For this reason it is necessary to assume that the light distribution from all the fittings along the runway is to be the same so that the same appearance will be presented wherever the aircraft comes in; this takes into account what are, in effect, vertical deviations above the ideal glide path.

(f) That lights which are at angles below 20 deg. depression from the aircraft are either cut off from view by the cockpit or their angular movement is so rapid that they do not form an effective part of the pattern which guides the pilot.

(1.3) Visibility Conditions

In clear weather it is relatively easy to provide lights of adequate conspicuity. When it is foggy the problem is much more difficult.

Meteorological visibility is defined internationally in terms of daylight visual range[3] which is defined as the distance at which a large, dark object seen against the horizon sky is just visible.

The daylight visual ranges, which are internationally used for observation and recording, are given in Table 1.

It can be shown from Koschmieder's law[4] that at this range the transmission to light of the air between the observer and the object is 2 per cent. This definition of visual range is not applicable to night conditions, nor does it apply to the visibility of light sources. These may have a high intrinsic brightness, and even when the atmospheric transmission is reduced to less than 2 per cent. may still be visible against their background[5]; consequently lights may, on occasion, be seen at distances greater than the daylight visual range. There is at present no agreed method of defining the visual range of light sources, and it is necessary to define the state of the atmosphere at night by referring to the equivalent daylight visual range. A given value of daylight visual range, together with Allard's law (see section 2), and Koschmieder's relation, make it possible to determine what candle-power is needed in a light source to produce a given illumination on the observer's eye.

The perception of a signal light, which appears as a point, is determined

Table 1.

Daylight Visual Ranges.

Description	Object just visible at	
Dense fog	25 metres	27 yds.
do.	50 ,,	55 ,,
Thick fog	100 ,,	110 ,,
do.	200 ,,	220 ,,
Moderate fog	500 ,,	550 ,,
Mist, haze or very poor visibility ...	1,000 ,,	1,100 ,,
Poor visibility	2,000 ,,	2,200 ,,
Moderate visibility	4,000 ,,	2¼ miles
,, ,, ...	7,000 ,,	4⅓ miles
Good ,, ...	10,000 ,,	6¼ miles
Very good ,, ...	20,000 ,,	12½ miles
,, ,, ,, ...	30,000 ,,	18¾ miles
Excellent visibility	50,000 ,,	31 miles

by the illumination which it produces at the eye; and many workers have quoted values for the lower practical limit under various conditions. Green gives the curve of Fig. 2, relating the limiting eye illumination to the background brightness, for a steady light just sufficiently visible as a signal when seen foveally. Stiles, Bennett and Green state that background brightnesses less than 10.3 c./ft.^{2} have no significant effect upon the limiting eye illumination for practical signals seen by foveal vision, and it will be seen from the curve that the effect is small up to 0.01 c./ft.^{2}.

Stiles, Bennett and Green also give typical values of background brightness, which are reproduced in Table 2.

Table 2.

Typical Values of Background Brightness.

Background	Approximate Brightness (Candles/sq. foot)
Starlit sky	5×10^{-5}
Moonlit sky	2×10^{-3}
Full moonlight on snow	7×10^{-3}
Ocean, towns, woods	60
Fields and ploughed land	130
Dry sand	250
Fog surface or snow	1,300
Daylight fog	300*

* There appears to be no agreed value of background brightness for daylight fogs: this figure is used by the Royal Aircraft Establishment in similar calculations. However, Kevern(11) gives a value of 10 candles per square foot.

The brightest background likely to be experienced at night is full moonlight on snow, which has a very small effect upon the limiting eye illumination. The value often taken for design purposes for a dark night is 0.5 mile-candle, which clearly allows a reasonable factor of safety for conditions at night. (See Fig. 2.)

Most of the experimental determinations(8) have been made with the

object of investigating the visual range of beacon signals. Under these conditions the pilot, although expecting to see the signal, has been regarded as having to scan a fairly wide angular field. When approaching a runway, the aircraft should be guided to a position close to the correct track by approach radio and lighting aids. The pilot should not, therefore, need to scan a wide field; he will instinctively look in the direction from which the contact lights will appear. It is possible then that a lower value than the generally accepted practical limit of 0.5 mile-candle could safely be taken, but this remains to be proved, and 0.5 mile-candle is used for the present calculations.

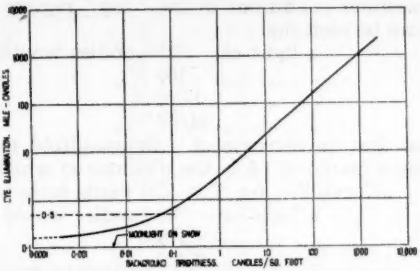

Fig. 2. Relation between eye illumination and background brightness for a just adequate signal. (Steady point source : Foveal vision.)

(1.4) Practical Limits of Intensity from Fittings

British practice is to use fittings which are set "flush" with the surface of the runway. The requirement(1) is that the fitting shall not stand more than 2.5 in. above the paved surface. Furthermore, the shape must be such that there is no possibility of damage to the tyres of an aircraft; the fitting must be mechanically strong enough to withstand the weight of an aircraft, and it must be watertight. A large number of British aerodromes, before and during the war, were equipped with flush type contact lights, each operated from isolating transformers on a high voltage ring main carrying 6.6 amperes. The series burning lamps which were used, consumed about 40 watts. This large amount of existing electrical equipment has naturally influenced new designs of contact light, and some immediate post-war designs have been based on a standard 6-volt 36-watt. car headlamp. Experience has indicated that with this lamp the maximum intensity obtainable from a flush-mounted contact light designed to meet these requirements is between 5,000 and 10,000 candles.

Summarising the foregoing, the basis of calculation is as follows:—

The "geometry" is shown in Fig. 1.

The "starting point" for the aircraft is when it is 100 feet high on a 3 deg. glide path.

The maximum intensity obtainable from the light is between 5,000 and 10,000 candles.

(2) Calculation of Light Distribution

The illumination E (mile-candles) due to a source of intensity I (candles) distant d (miles) in an atmosphere whose transmission is T per mile is

$$E = \frac{I}{d^2} T^d \quad \text{(Allard's law)}$$

$E = 0.5$ mile-candles is taken as the eye illumination at which a light source can just be seen clearly. The weather condition is defined by the relation $T^V = 0.02$ when V is the daylight visual range in miles as defined previously.

Fig. 3 gives the relation between I and d (expressed in feet) for $E = 0.5$ mile-candles for two values of V in the relation $T^V = 0.02$ corresponding to

weather conditions in the "fog" region. Curve 1 is for V = 110 yards, and it can be seen that:

a light of	10	candles	would	be	visible	at	about	620	ft.
„ „ „	100	„	„	„	„	„	„	775	„
„ „ „	1,000	„	„	„	„	„	„	930	„
„ „ „	10,000	„	„	„	„	„	„	1,100	„

so that an increase of a thousandfold in intensity has resulted in an increase by a factor of 1.8 in the distance at which the light would be visible.

Curve 2 is for V = 220 yards from which it can be seen that:

a light of	10	candles	would	be	visible	at	about	1,040	ft.
„ „ „	100	„	„	„	„	„	„	1,350	„
„ „ „	1,000	„	„	„	„	„	„	1,670	„
„ „ „	10,000	„	„	„	„	„	„	2,000	„

A thousandfold increase in intensity gives an increase in the range by a factor of 1.9.

Fig. 4 shows the distances of fittings along the runway from an aircraft on a 3 deg. glide path. For an aircraft at the limiting height of 100 ft. its distance from the third fitting is approximately 1,100 ft. From the figures above, the necessary intensity from the third fitting in order that it may be easily visible on a dark night is:

about 10,000 candles when the weather is equivalent to D.V.R.* 110 yards
„ 10 „ „ „ „ „ „ „ „ 220 „

Both of these visibility ranges are described as "thick fog" and for normal meteorological purposes it is not necessary to distinguish between them. In fact, variations in fog density of the same order may occur in practice over the

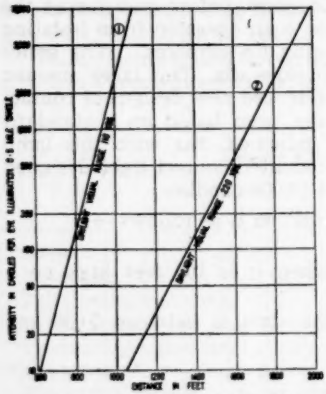

Fig. 3 *(left)*. Relation between distance and intensity necessary to give eye illumination of 0.5 mile-candles.

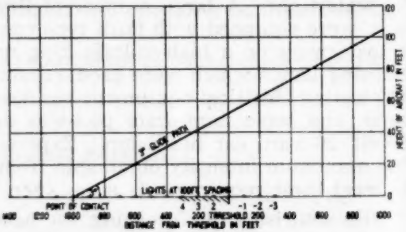

Fig. 4 *(above)*. Path of aircraft approaching at 3°.

length of the approach path and runway. It appears, therefore, that although it is possible to state a meteorological daylight visual range below which a given lighting arrangement will not serve, this range will be critical to variations of a few yards, and it is not practicable to take account of such small variations. To compute the shape of the light distribution required it is, however, necessary to make this assumption.

From the foregoing and from Fig. 3 it is possible to state the minimum candle-power required from each fitting to produce the minimum (0.5 mile-candle) eye illumination, the position of the aircraft and the atmospheric condition being given. Table 3 gives a list of candle-power values for atmo-

*Daylight Visibility Range.

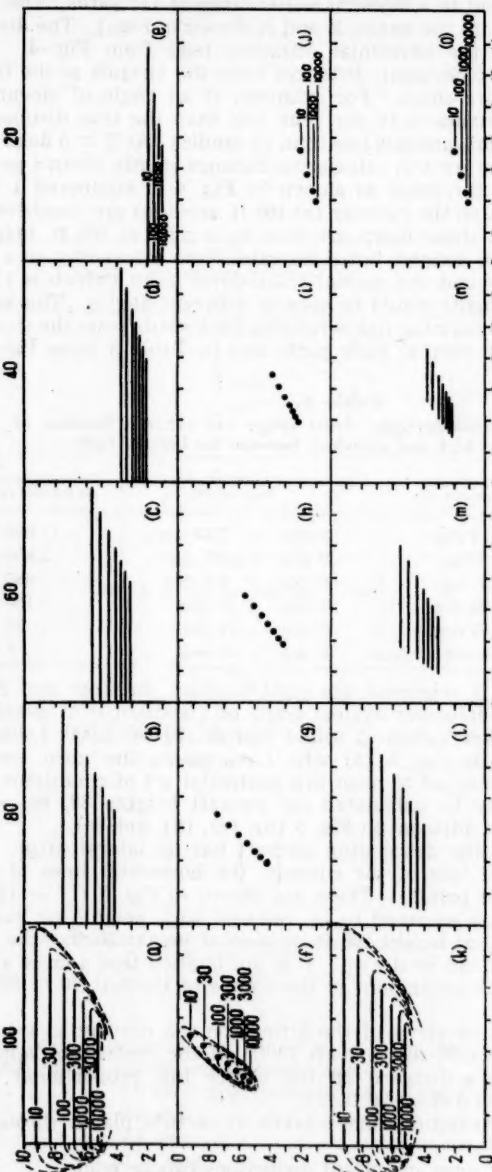

Fig. 5. Calculated isocandle diagrams for runway contact lights. Weather condition equivalent to daylight visual range 110 yards. Intensity values in candles for eye illumination 0.5 mile-candle.

(a)—(e) Aircraft between 0 and 75 ft. sideways from centre line.
(f)—(j) Aircraft over centre line at all heights.
(k)—(o) Maximum distance sideways from centre line varying with height. (75 ft. at 100 ft. and 0 ft. at 20 ft.)
(Broken lines in (a), (f) and (k) show estimated positions of isocandle contours.)

spheric condition equivalent to a daylight visual range of 110 yards. The angles of elevation and azimuth are the angles E and A shown in Fig. 1. The distances used for calculation are the horizontal distances read from Fig. 4. These are slightly less than the true, slant, distances from the aircraft to the fittings, but the errors involved are small. For example, at an angle of elevation of 20 deg. the horizontal distance is 16 per cent. less than the true distance, but the intensity required at this angle is less than 10 candles. At E = 5 deg., where the intensity is critical, the error in calculating distance is only about 1 per cent. The nearest light to the threshold as shown in Fig. 4 is numbered 1 in the table, and the other lights on the runway (at 100 ft. spacing) are numbered 2, 3, etc. The angles at which these lights are seen by a pilot at 100 ft. height on a 3 deg. glide path are now defined; but if the pilot were descending on a 3 deg. glide path terminating beyond the normal touch-down point (which is 1,000 ft. from the threshold) the lights would be seen at different angles. This may be studied conveniently by imagining lights ranging backwards from the threshold as seen by a pilot on the normal glide path, and in Table 3 these lights are referred to as -1, -2, -3.

Table 3.

Atmospheric conditions—daylight visual range 110 yards. Position of aircraft—100 feet high and anywhere between the lines of light.

Fitting	Angle of Elevation (E)	Angles of Azimuth (A)	Intensity (candles) for 0.5 mile candle
3	5.17 deg.	0 deg. to 7.73 deg.	11,000
2	5.7 deg.	0 deg. ,, 8.5 deg.	2,800
1	6.3 deg.	0 deg. ,, 9.4 deg.	680
—1	7.08 deg.	0 deg. ,, 10 deg.	160
—2	8.07 deg.	0 deg. ,, 12 deg.	37
—3	9.4 deg.	0 deg. ,, 13 deg.	8

The figures of Table 3 represent the light distribution from any contact light and by plotting candlepower against angle of elevation it is possible to interpolate for candlepower values in round figures (10,000, 3,000, 1,000, etc.). These have been plotted in Fig. 5 (a) which represents the ideal isocandle distribution for fittings designed to meet this particular set of conditions.

Similar diagrams may be calculated for aircraft heights 80, 60, 40 and 20 ft. and these are shown adjacent in Fig. 5 (b), (c), (d) and (e).

If it is assumed that the descending aircraft has no lateral error, i.e., it is always over the centre line of the runway, the horizontal lines of Fig. 5 (a) — (e) shrink to single points. These are shown in Fig. 5 (f) — (j). If the possible lateral error is assumed to be reduced with height, for example, from a maximum of 75 ft. at height 100 ft. to zero at height 20 ft.,* the set of diagrams Fig. 5 (k) — (o) can be drawn. It is not implied that a large aircraft could be corrected by such an amount in the course of the last 70 to 80 ft. of its descent.

Fig. 6 shows perspective views of the fittings on the runway as seen from heights 100, 60 and 20 ft. with the aircraft 75 ft. off the centre line approach, over the centre line and a distance off the centre line proportional to the height (75 ft. at 100 ft. and 0 ft. at 20 ft.).

Fig. 7 shows light distribution curves taken in vertical planes through the diagrams of Fig. 5.

From Figs. 5, 6, and 7 some important deductions can be made.

* The pilot's eye may be 20-30 ft. above the runway when the aircraft is taxi-ing, but these figures form a useful basis for calculation.

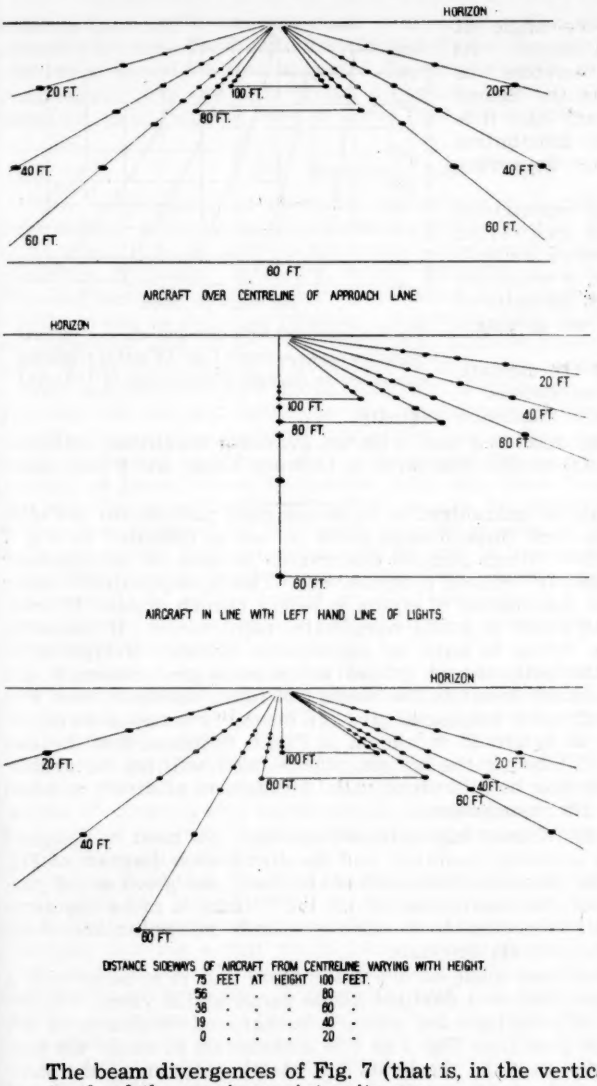

Fig. 6. Perspective views of lines of lights seen from various heights. (Perspective distance 3½ inches.)

The beam divergences of Fig. 7 (that is, in the vertical plane) measured to one-tenth of the maximum intensity are:—

0.9 deg.	approximately	for	height	100 ft.
0.8 deg.	,,	,,	,,	80 ,,
0.6 deg.	,,	,,	,,	60 ,,
0.35 deg.	,,	,,	,,	40 ,,
0.2 deg.	,,	,,	,,	20 ,,

A "practical" fitting for runways would have a light distribution

symmetrical about the angle at which 10,000 candles occurs. Its divergence would, therefore, be approximately double the figures given above and in any case it is doubtful whether the distribution could be made to match these very critical curves.

The limiting case is represented by the diagrams (a) and (k) of Fig. 5 and the 100 ft. curve of Fig. 7. The angle in elevation at which the direction of maximum intensity of the fitting must be set is determined by:—

the height of the aircraft,
the weather conditions,
the value of the maximum intensity.

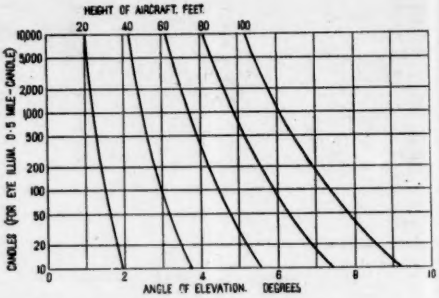

Fig. 7. Calculated light distributions in a vertical plane for runway contact light. (Weather condition equivalent to daylight visual range of 110 yds.)

For the conditions described and with an available maximum intensity between 5,000 and 10,000 candles, this angle is between 5 deg. and 6 deg. above the horizontal.

If the aircraft could be guaranteed to be on the glide path shown in Fig. 4, the peak angles of the first three fittings could be set as indicated in Fig. 7 and those of the further fittings stepped downwards in turn, or alternatively the peak intensity would be reduced progressively. This is impracticable since it would not cover the contingency of errors in height (which amount to overshooting the glide path) and it would complicate maintenance. If, however, it is possible for the fitting to have an appreciable vertical divergence at maximum intensity the beam should extend below an angle between 5 and 6 deg. so that as the aircraft descends, the number of lights visible on each side will increase rapidly, thereby helping to give the necessary sense of direction. The perspective view at height 20 ft., shown in Fig. 6, indicates that the two lines are, in fact, not far below the horizon, which itself will not be visible; it will therefore in any case be difficult to make a judgment of direction when taxi-ing at speed just after touchdown.

The light distribution from a high intensity contact light must be designed to meet some limiting visibility condition, and the distribution diagram of Fig. 5a is an example of the theoretical requirement to meet one given set of conditions. Assuming that the distribution of all the fittings is to be the same it is not, even theoretically, possible to achieve a uniform appearance of all the lights visible as the aircraft descends.

The calculation has been made on the assumption that it is dark, with a weather condition equivalent to a daylight visual range of 110 yards. If the lights are to be seen in a daylight fog giving a background brightness of 300 candles per square foot then from Fig. 2 an eye illumination of about 400 mile candles would be needed to make the lights just visible. Assuming the same maximum available candlepower and the same viewing distance it is found that the greatest fog density in which the lights can be seen is that equivalent to a daylight visual range of about 270 yards.

The design of runway lights is based primarily on the landing procedure, but if the light distribution is suitable for landing it will also be suitable for the initial stages of take-off. The extent to which the lights can be of assistance after the initial stage obviously depends on the length of the runway and the

distance travelled before the craft is airborne. The view of the pilot will probably be somewhat more restricted because the aircraft is in a climbing attitude and as the height increases the runway lights, even if visible, will be progressively less useful in giving a horizon. In the later stages of take-off, therefore, guidance will have to come from other lights or from instruments.

(3) Practical Contact Light

The mechanical and electrical limitations on present designs of contact light fittings were discussed in section (1.6) by way of explanation of the use of an upper limit of 5,000—10,000 candles for the purposes of calculation. The maximum intensity obtainable, rather than the distribution, is in fact the deciding factor; the main object is to ensure that a few lights at least will be visible in fog as dense as possible. A contact light is, therefore, in the class of projectors; and its peculiar mechanical features involve a low light output ratio in the main beams. Given limited beam lumens and a requirement for a high maximum candle-power, the light distribution is a matter for compromise; and the best result can only be determined by experiment.

Fig. 5 and the assumption behind it indicates that the region of maximum intensity should be spread over a horizontal fan about 8 deg. wide, to take account of lateral errors in position, and that, given this width, any "spare" flux in the peak intensity region should be devoted to increasing the divergence downwards. This will mean that even if the pilot sees at first only one or two lights on either side he will be reassured a few seconds later by seeing more as he descends a few feet. In this argument the emphasis has been placed on the lateral error—if the aircraft is far off the centre line the pilot may not see the lights at all unless a reasonably wide horizontal beam divergence is provided.

An alternative argument is that by the time the aircraft has descended to 100 ft. the approach aids will have centred the aircraft to within much closer limits than plus or minus 75 ft. In this event the "spare" light flux in the peak intensity region may be used for obtaining a wider vertical beam divergence both below and above the optimum angle. The former is valuable for the reason given earlier, the latter because a high intensity at higher angles of elevation may enable a pilot to see lights under even worse fog conditions. The resultant beam would thus approximate to a vertical fan rather than a horizontal one.

It is argued that a wide horizontal beam will cause glare when the aircraft is close to the ground. This is obviously academically true; but it does not seem likely that the effects will be such as to upset the pilot's judgment while carrying out the actual touch-down procedure. This procedure admittedly calls for skill and cool nerves in manoeuvring the aircraft, but as a visual task the operation is simple. It is certain that if a wide angle beam is desirable for the earlier stages of the approach some glare is inevitable when the aircraft is running along the ground, and this may still be serious even if the power in the light is controlled by a dimmer.

Fig. 8 illustrates one recent design of fitting. It is formed of a square cast-iron base in which is housed the principal optical component. This is a spun aluminium paraboloidal reflector, with its axis vertical, having a 6-volt, 36-watt headlamp whose axial (line) filament is at the focus of the reflector. The vertical beam formed is intercepted by two cylindrical reflectors mounted on the cast-iron lid of the fitting. This lid is supported on four lugs upstanding from the main casting. The aperture between the upper and lower castings

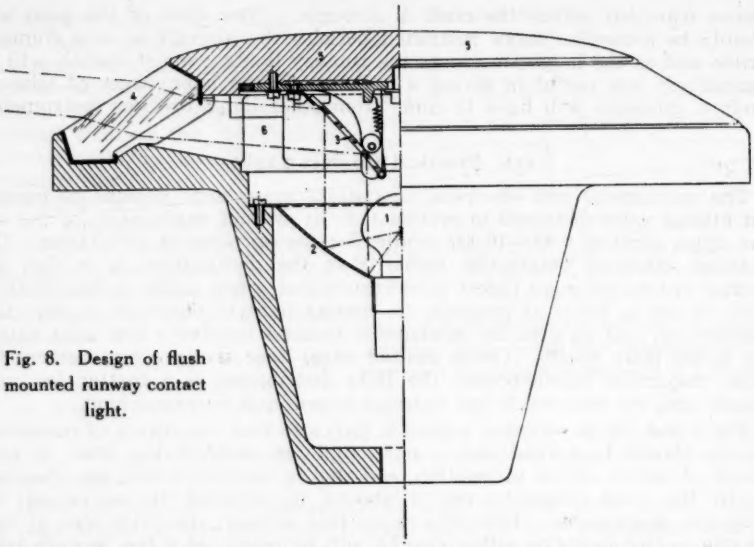

Fig. 8. Design of flush mounted runway contact light.

is closed by a glass ring which, when the lid is clamped down, is compressed between rubber gaskets so that the fitting is rendered watertight.

The mounting of the upper reflectors on the underside of the cast-iron lid is so arranged that the beam may be adjusted both in elevation and in azimuth. The elevation is adjusted at the works. The light distribution, which is shown in Fig. 9, is a compromise between the theoretical requirements of Fig. 5 (a)—(e) and (f)—(j).

Since the light distribution is critical the lights must be mounted accurately on the runway or the value of the accurate optical components and their precise assembly will be wasted.

(4) Flush and Elevated Types of Contact Light Fitting

Fittings developed in America during the last few years take the form of pressed prismatic glasses mounted on a stem some 3 feet above the ground and placed along the edges of the paved runway. This type of equipment, using lamps of as much as 300 watts, was used in this country by the American Forces during the war, but has never found favour with the British authorities.

The principal advantages of such large fittings as this are:—

(a) The lamp wattage is less limited than in the flush lights of reasonable size.

(b) There is freedom of optical design which can give precise control of the form of the light distribution.

(c) Intensities of the order of a 100,000 candles may be obtained.

(d) They may be arranged to stand high enough to be clear of snow.

(e) The equipment needs to be less strong than when flush mounted, and it is simpler to make it watertight.

The disadvantages are:—

(a) That they represent an obstruction to landing or taxi-ing aircraft—this is the principal ground of objection in this country.

(b) Because they are an obstruction the fittings must be placed off the

paved runway and, as a result, the pattern of the lights will vary with the width of the paving. Suppose, for example, that on one aerodrome the lights in each line were spaced at 100 ft. on a runway 150 ft. wide, and on another they were spaced at 200 ft. on a runway 300 ft. wide. Then the appearance of the pattern in the one runway from 50 ft. high would be the same as the appearance on the other from 100 ft. If conditions were such that only the runway lights were visible the pilot's visual judgment of height might be in error unless he could remember which arrangement of lights was installed at the aerodrome where he was landing. It is, therefore, regarded as important that this pattern should be identical for all aerodromes, and attempts are being made to achieve international agreement.

(c) The line of fittings must be broken at runway or taxi-way intersections. On an aerodrome where the runways are 300 ft. wide the gap resulting may be as much as 800 ft. or 900 ft., and if there is a group of taxi-ways leading off the runway to a parking area the line may be broken irregularly at many points.

In countries where heavy snowfall occurs frequently it is the practice to to compact the snow and use it as a landing surface. In these circumstances the only solution, if a permanent installation is required, is to use elevated fittings. An alternative is to use a portable type (such as the Type 6 flarepath unit[9]), but these do not give the high intensities required for heavy fog.

It has still to be proved whether very high intensities, i.e., up to 100,000 candles are necessary. The figures given earlier show that in thick fog the increase of intensity has to be very large, for even a small increase in range.

From Fig. 3 it may be shown that an increase from 10,000 to 100,000 candles would increase the visibility range of the lights by 150 ft., when the daylight visibility range is 110 yards; that is it would increase the number of lights visible in each row by one only.

Obviously there is some economic limit determined by the chance of such fog occurring, and the economics of power supply and cabling. Furthermore, there is a limiting range beyond which the contact lights need not be seen. A great deal of development work on approach lighting systems is being carried out both in England[10] and in America[11, 12, 13], and when this work is completed it should be possible to determine the limiting range necessary for contact light fittings.

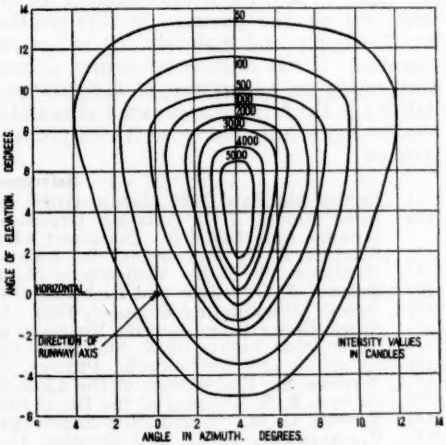

Fig. 9. Light distribution of a flush mounted contact light.

(5) Light Distribution at Angles other than the Direction of Landing

There has been much discussion about the light distribution in directions other than those from which the contact light is seen during approach and landing. The principal object is to enable the pilot to see the lie of the runway when making a circuit and, presumably, if the flying of circuits prior to landing

were discontinued, there would be no object in runway fittings emitting light in other directions. Assuming, however, that circuits are flown the matter may be discussed under three headings:—

(a) In heavy fog; (b) in clear weather; (c) in conditions intermediate between (a) and (b).

In heavy fog it is evident from the previous sections that there is no possibility of the lights being visible from any other than the direction of approach.

In clear weather there is no difficulty in providing the necessary light intensity—some 10-20 candles are adequate. It is not certain, however, that a fitting adapted for (a) will serve both purposes. All installations of high intensity contact light will be provided with dimmers to adjust the intensity to suit the prevailing weather. As the lights are dimmed they will become redder: this imposes a limit on the permissible dimming, and it is possible that in clear weather the lights will still be glaring when this limit is reached. Assuming the mechanical and electrical limitations discussed previously a high-intensity fitting can be made to meet "all round" requirements only by sacrificing its performance in fog.

For clear weather then, one solution is to use a separate low-intensity fitting with a 360-deg. distribution of light.

A low-intensity fitting with a 360-deg. distribution could be made to serve in conditions intermediate between clear and thick fog. As an example, if the daylight visual range is 1,100 yards ("mist or haze"), lights of intensity 30-40 candles would be easily visible from the approach, but on a circuit of radius one mile the intensity needed for them to be just visible (i.e., at eye illumination 0.5 mile-candle) would be 260 candles. Apparently, then, the runway lights should have their maximum intensity in a direction at right angles to the runway. In other words, their main function is no longer in connection with approach and touch down, but as a navigational aid when flying a circuit.

It would be better to restrict runway lights with all their associated mechanical and electrical problems to the function of take-off, approach and touch down. If it is required to show the lie of the runway from all directions two lines of, say, six lights designed for the purpose should be placed parallel with, but off, the paving. In this position they would be relatively easy to install, supply and maintain. It is not certain that this form of markings is essential. It has often been argued as necessary, but the argument may have been based on experience of aerodromes where there was little or no other lighting in the form of approach lights and identification beacon. As aerodromes become more fully equipped it will probably be found that these will serve the purpose.

References

(1) British Standard 1332 (1946). Guide to Civil Land Aerodrome Lighting.
(2) International Civil Aviation Organisation. Aerodromes, Air Routes, and Ground Aids Division. Document 4809.
(3) Sutcliffe, R. C. Meteorology for Aviators, p. 47 (H.M. Stationery Office).
(4) Middleton, W. E. K. Visibility in Meteorology (University of Toronto Press).
(5) Holmes, J. G. Light and Lighting, 1943. Vol. 36, p. 23.
(6) Green. Illuminating Engineer, 1935. Vol. 28, p. 146.
(7) Stiles, Bennett, and Green. Visibility of Light Signals with Special Reference to Aviation Lights (H.M. Stationery Office).
(8) Langmuir and Westendorp. Physics. 1931. Vol. 1, p. 273.
(9) English, S. Proceedings of the I.E.S. Convention. 1946, p. 73.
(10) Calvert, E. S. Journal of the Royal Aeronautical Soc., July, 1948, p. 439.
(11) Kevern, G. M. Illuminating Engineering, 1946. Vol. XLI, No. 6, p. 455.
(12) Breckenridge, F. C., and Douglas, C. A. Illuminating Engineering, 1945. Vol. XL. No. 9, p. 785.
(13) High Intensity Approach Lights, 1946. Fog Season Report. Landing Aids Experiment Station, Arcata.

Additions to List of Members

The following applicants have been duly elected by the Council to membership in the Society, and their names have been added to the list of members:—

SUSTAINING MEMBERS:—

Midlands Electricity Board .....*Representative*: H. J. Gibson. (Walsall District), Bridge Street, WALSALL.

South-Western Electricity Board .....*Representative*: G. W. Richards. Electricity House, Colston Avenue, BRISTOL.

CORPORATE MEMBERS:—

Albini, C. .....147a, Earls Court Road, KENSINGTON, S.W.5.
Eshmade, A. J. .....25, Urlwin Street, CAMBERWELL, S.E.5.
Harrison, R. W. .....39, Normanby Road, Ormesby, Middlesbrough, YORKS.
Hitchin, F. .....12, Nearbrook Road, Brownley Green, MANCHESTER.
Nampon, R. .....9, Rue Antoine Bourdelle, Paris 15e, FRANCE.
Roberts, K. M. .....Redhaven, Moor Road, Glen Holt, nr. Crownhill, DEVON.
Shepherd, P. E. O. .....80, Toynbee Road, WIMBLEDON, S.W.20.
Turner, R. A. .....10, Queens Court, UPPER NORWOOD, S.E.19.

COUNTRY MEMBER:—

Kreps, I. .....66, Herzl Street, Haifa, PALESTINE.

STUDENT MEMBER:—

Watts, P. I. ....." Granville," Highfield Road, Westerhope, NEWCASTLE-ON-TYNE.

The Illuminating Engineering Society is not, as a body, responsible for the opinions expressed by individual authors or speakers.

With a view to avoiding possible confusion with other publications, reference to these Transactions should be in the form:—" Trans. Illum. Eng. Soc. (London)."

I.E.S. Regional Committees

Session 1948—1949

Centres:

BATH AND BRISTOL CENTRE (WESTERN AREA).

Chairman: L. Burdes. *Vice-Chairman:* W. C. Bowler. *Hon. Treasurer:* R. G. Capell. *Committee:* D. E. Beard, H. Foster, A. E. Hayward, E. A Newburn, S. Poole, C. W. Rawlings, I. M. Robertson, H. Tabb, W. L. Tout, R. E. Tucker, H. Weston, J. West. *Hon. Secretary:* R. S. Hazell, c/o The General Electric Co. Ltd., Lawford Street, Old Market, Bristol 2.

BIRMINGHAM CENTRE (MIDLAND AREA).

Chairman: Dr. J. H. Nelson. *Vice-Chairman:* P. Hartill. *Hon. Treasurer:* J. Ashmore. *Press Liaison Officer:* F. E. Chapman. *Committee:* F. S. Ette, J. Forth, V. Heydon, Dr. A. J. Holland, S. D. Lay, R. A. Lovell, F. Penson, W. H. Randall, G. Satchwell. *Hon. Secretary:* W. J. P. Watson, 91, Brandwood Road, Kings Heath, Birmingham, 14. *Hon. Asst. Secretary:* W. E. Prendergast.

CARDIFF CENTRE (SOUTH WALES AREA).

Chairman: S. G. Turner. *Vice-Chairman:* J. S. Childs. *Committee:* J. Trevor Jones, J. S. Liversage, E. N. Lockyer, G. R. Lusty, H. W. Mabbett, J. H. Parker, H. W. Rees, R. E. Silvey, C. E. Springsguth, W. H. Stone, V. R. Treasure, V. G. Wackrow. *Hon. Secretary and Treasurer:* N. D. Houston, 54, St. Mary Street, Cardiff.

EDINBURGH CENTRE (SCOTTISH AREA).

Chairman: S. G. Batt. *Vice-Chairman:* H. D. Purvis. *Hon. Treasurer:* H. Stanway. *Committee:* L. R. Brown, H. Buckley, J. S. Galbreath, I. W. Hunter, C. Norman Kemp, W. Mackenzie, C. K. Ross. *Hon. Secretary:* G. E. L. Comrie, 4, Silverknowes Terrace, Edinburgh, 4.

GLASGOW CENTRE (SCOTTISH AREA).

Chairman: D. Ross, *Vice-Chairman:* A. MacGregor. *Hon. Treasurer:* J. Welsh. *Committee:* T. Dunnett, A. Kelso, C. J. King, J. Langlands, J. M. Henshaw, E. J. Stewart, A. B. Wright. *Hon. Secretary:* A. M. Rankin, 53, Pitt Street, Glasgow, C.2.

GLOUCESTER AND CHELTENHAM CENTRE (WESTERN AREA).

Chairman: J. Davoile. *Vice-Chairman:* W. Holtam. *Hon. Treasurer:* H. V. Sayce. *Committee:* B. J. Dyer, J. F. Edgell, G. R. Hadley, W. Hill, B. C. Mitchell, L. C. Mitchell, I. R. Morgan, W. T. Turner, H. V. Williams. *Hon. Secretary:* I. S. Freemantle, 33, Church Road, Longlevens, Gloucester.

LEEDS CENTRE (NORTH MIDLAND AREA).

Chairman: J. D. Green. *Vice-Chairman:* T. C. Holdsworth. *Hon. Treasurer:* A. Wilde. *Committee:* J. R. Bardsley, E. Bastow, E. A. Fowler, R. D. Green, H. W. Harris, P. C. Harrison, J. W. Howell, A. G. Smith, E. Smith, S. K. Spencer, E. C. Walton, J. H. Weaver. *Hon. Secretary:* A. Wilcock, 49, Bazinghall Street, Leeds, 1. *Asst. Hon. Secretary:* E. Bastow.

LEICESTER CENTRE (MIDLAND AREA).

Chairman: F. Jamieson. *Vice-Chairman:* R. K. L. Davies. *Hon. Treasurer:* F. J. Stanyon. *Committee:* F. A. Bell, E. C. Came, P. H. H. Jantzen, H. H. S. Mansfield, R. H. Phillips, G. C. B. Webb, T. Wilkie. *Hon. Secretary:* W. N. Coulson, 5, Campbell Street, Leicester.

LIVERPOOL CENTRE (NORTH WESTERN AREA).

Chairman: O. C. Waygood. *Vice-Chairman:* C. C. Smith. *Hon. Treasurer:* W. T. Trace. *Committee:* R. W. J. Benyon, N. Blackman, P. Bregazzi, F. G. Copland, E. M. Duke, L. G. Harris, Tom Jones, K. E. Pickard, F. W. White, A. Winstanley, T. D. Woods. *Hon. Secretary:* K. R. Mackley, Inner Temple, 24, Dale Street, Liverpool. *Asst. Hon. Secretary:* F. J. Burns.

MANCHESTER CENTRE (NORTH WESTERN AREA).

Chairman: H. Atherton. *Vice-Chairman* F. J. R. Makin. *Hon. Treasurer:* H. Etchells. *Committee:* W. C. G. Bailey, F. S. Boucher, E. J. Bull, W. G. Chilvers, Mrs. I. H. Hardwich, J. Martin, T. Metcalfe, J. H. Morrison, T. L. Robinson, J. Walsh, H. Wilcock. *Hon. Secretary:* W. E. Ballard, "Fair Rigg," Fairview Road, Timperley, Cheshire. *Asst. Hon. Secretary:* Alan H. Owen.

NEWCASTLE CENTRE (NORTH EASTERN AREA).

Chairman: H. L. James. *Vice-Chairman:* A. J. Ogle. *Hon. Treasurer:* J. Stewart. *Committee:* L. Charlton, W. H. Dodgson, C. Fielding, R. W. Gregory, G. R. Hanson, A. S. Lowery, J. S. McCulloch, W. Sancto, P. S. J. Underwood. *Hon. Secretary:* D. L. Tabraham, 25, The Drive, Gosforth, Newcastle-on-Tyne.

NOTTINGHAM CENTRE (MIDLAND AREA).

Chairman: W. K. Martin. *Vice-Chairman:* R. H. Ellis. *Hon. Treasurer:* P. L. Ross. *Committee:* J. C. Charity, G. Honnorarty, A. G. Kidd, A. R. Law, R. G. Mountford, E. G. Phillips, R. J. Pickford, N. C. Slater, G. C. Small, F. Walker. *Hon. Secretary:* A. Hacking, 32, St. Leonard's Drive, Wollaton, Nottingham.

SHEFFIELD CENTRE (NORTH MIDLAND AREA).

Chairman: B. Bingham. *Vice-Chairman:* H. B. Leighton. *Hon. Treasurer:* C. Hadfield. *Committee:* J. G. Charlton, H. Dick, D. H. Fox, B. B. Hayter, H. Lewis, G. E. Rodger, W. G. Symons, E. G. R. Taylor, W. G. Thompson, G. L. Tomlinson, H. Wheeler, A. Wylie. *Hon. Secretary:* M. G. Lockwood, 12, James Andrew Crescent, Greenhill, Sheffield 8.

Groups:

BRADFORD GROUP (NORTH MIDLAND AREA).

Chairman: W. B. Jamieson. *Committee:* T. N. Hird, H. Moss, W. H. Naylor, A. S. Redvers Pratt, N. Rhodes, L. Robinson, J. H. Rogerson, F. S. Warburton. *Joint Hon. Secretaries:* A. J. Hutchison, 45/53, Sunbridge Road, Bradford, W. H. Naylor, 40, Godwin Street, Bradford.

EXETER GROUP (WESTERN AREA).

Chairman: F. D. Newcombe. *Committee:* D. R. Beckett, H. H. Brown, W. E. Browning, H. T. Corrigan, C. Lye, L. D. H. Rowe, F. W. Sansom. *Hon. Secretary:* L. W. Cornish, 46, North Street, Exeter.

HUDDERSFIELD GROUP (NORTH MIDLAND AREA).

Chairman: H. L. Walker. *Vice-Chairman:* M. E. Broadbent. *Committee:* F. Eastwood, R. Hardy, G. Ripley, W. Robinson, N. Schofield, E. C. J. Swabey, J. T. Thornton, H. Walton. *Hon. Secretary:* E. Wood, 11, Long Grove Avenue, Dalton, Huddersfield,

STOKE ON TRENT GROUP (MIDLAND AREA).

Chairman: T. Lockett. *Vice-Chairman:* E. N. Farnsworth. *Committee:* F. Claxton, W. A. Fisher, A. Gould, J. R. Piggott. *Hon. Secretary:* J. P. Oliver, 31, Kingsway, Stoke-on-Trent.

SUSSEX GROUP.

Chairman: E. Stroud. *Committee:* H. Barlow, R. Davidson, C. F. Green, V. B. J. Green, A. F. Harvey, M. W. Hime, R. T. Maundrell, J. R. Yeats. *Hon. Secretary:* F. Hampton, 41a, Warwick Street, Worthing. *Hon. Asst. Secretary:* A. P. Cole.

TEES-SIDE GROUP (NORTH EASTERN AREA).

Chairman: N. Hunter. *Vice-Chairman:* D. B. Hogg. *Hon. Treasurer:* G. H. J. Sansom. *Committee:* K. Graham, J. Kirby, R. K. Leslie, R. W. Oxley, M. A. Raisbeck, S. O. Shircore. *Hon. Secretary:* J. M. Sandford, Magnet House, Corporation Road, Middlesbrough.

Printed by
ARGUS PRESS, LTD.,
Temple-avenue and
Tudor-street,
London, E.C.4.,
England